# CAAP Quarterly Report

Date of Report: *June 30th, 2019*

Contract Number: *693JK318500010CAAP*

Prepared for: *U.S. DOT Pipeline and Hazardous Materials Safety Administration*

Project Title: Brain-Inspired Learning Framework to Bridging Information, Uncertainty and Human-Machine Decision-Making for Decoding Variance in Pipeline Computational Models

Prepared by: *North Dakota State University*

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For quarterly period ending: *July 7th, 2019*

## Business and Activity Section

### (a) Generated Commitments

Kickoff meeting was held at North Dakota State University on June 11st, 2019

No changes to the existing agreement

Some purchase of steel plates and piezoelectric sensors

Dr. Lin attended and presented the poster sections in World Techconnect 2019 on June 17-19.

### (b) Status Update of Past Quarter Activities

In the third report, the major work aimed to increase sample design and laboratory test associated with varying mechanical damages, while numerical simulation enriched datasets for mechanical damage, as summarized below:

## 1.1 Numerical simulation

### *1.1.1 Prototype*

The aim of the numerical study was to systematically investigate the Lamb wave-based damage detection methodology and yield the calibrated datasets. Finite element method was used to simulate the Lamb wave propagation and scattering in steel plates. The prototype was a steel plate with a rectangular shape in a dimension of 5 by 10 inch. Steel AISI 4340 in COMSOL was selected for the steel plate. The models with different states were investigated under a lamb wave excitation that was a five circles sine function operated with a hanning window and the frequency was 250 kHz (see Figure 1).

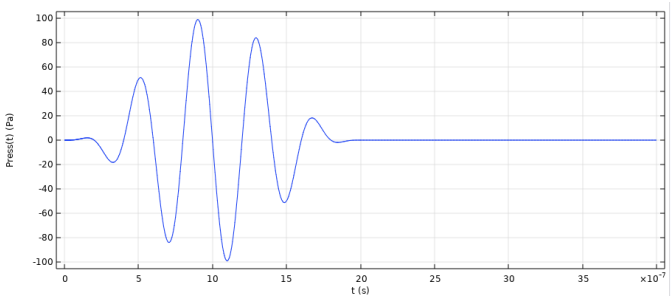


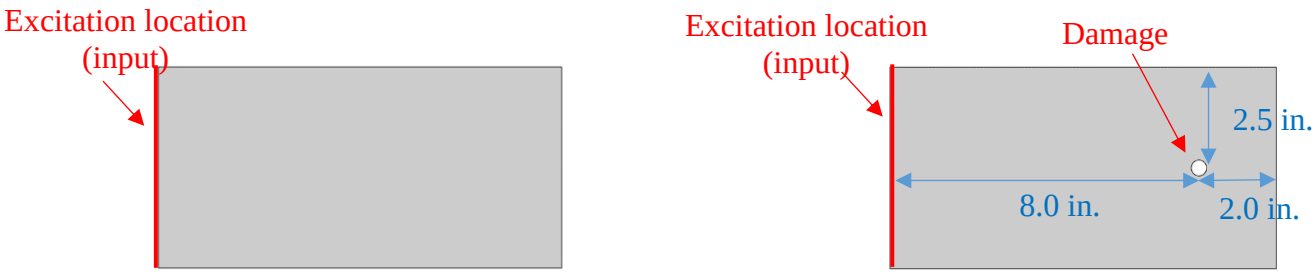

Fig. 1 Lamb-wave mode excitation as an input signal

### *1.1.2 Scenarios with different excitation modes*

The undamaged and damaged states were designed for the case analysis. The through-thickness circular hole with 0.2-in. radius was drilled in the steel plate to simulate the predetermined damage, which was in the right side of the plate, by 2.5 inches away from the upper side and 2 inches away from the right side, as shown in Fig. 2.

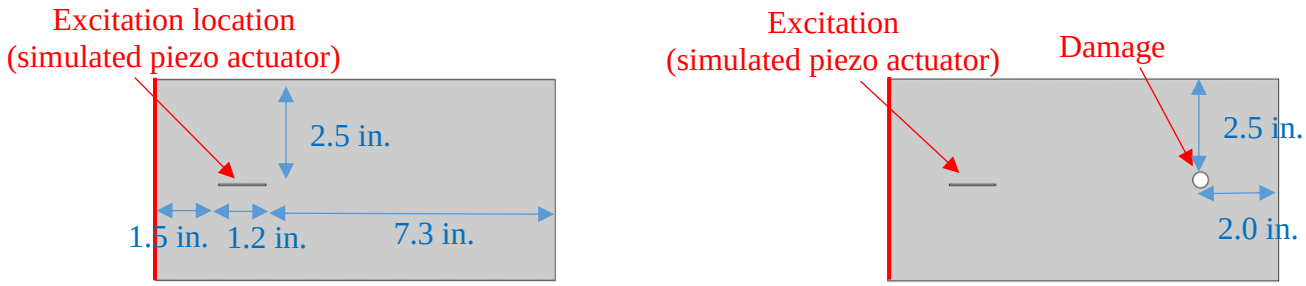
By considering the potential loading approaches, four different cases, illustrated in Figs. 2-3, were designed to optimally determine which was the effective way to capture more sensitive response and discussed in detail in Sections 1.2.1-1.2.2:

a) Lamb-wave excitation with the impulse pressure from left side (see Fig. 2)
b) Lamb-wave excitation with the impulse pressure from simulated piezo actuator (see Fig. 3)
c) Lamb-wave excitation with the impulse displacement from left side (see Fig. 2)
d) Lamb-wave excitation with the impulse displacement from simulated piezo actuator (see Fig. 3)




(a) Undamaged state (b) Damage state

Fig. 2 Lamb-wave excitation with the impulse pressure/displacement from left side



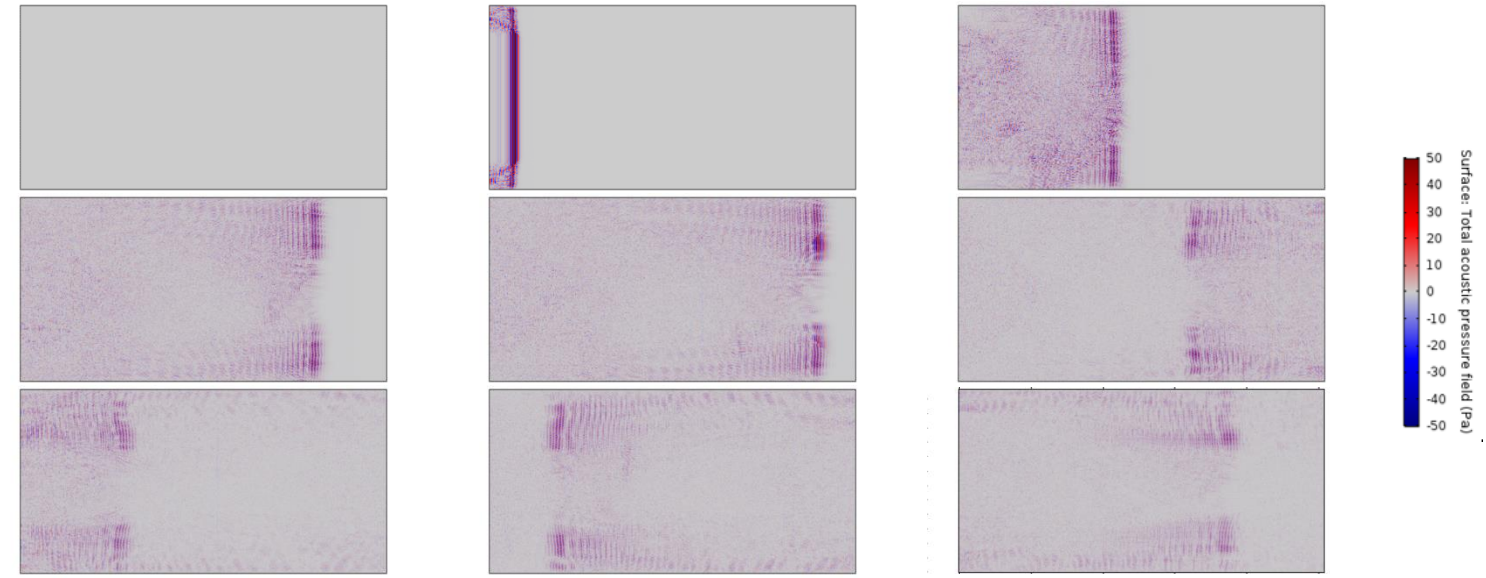

(a) Undamaged state (b) Damage state

Fig. 3 Lamb-wave excitation with the impulse pressure/displacement from simulated piezo actuator

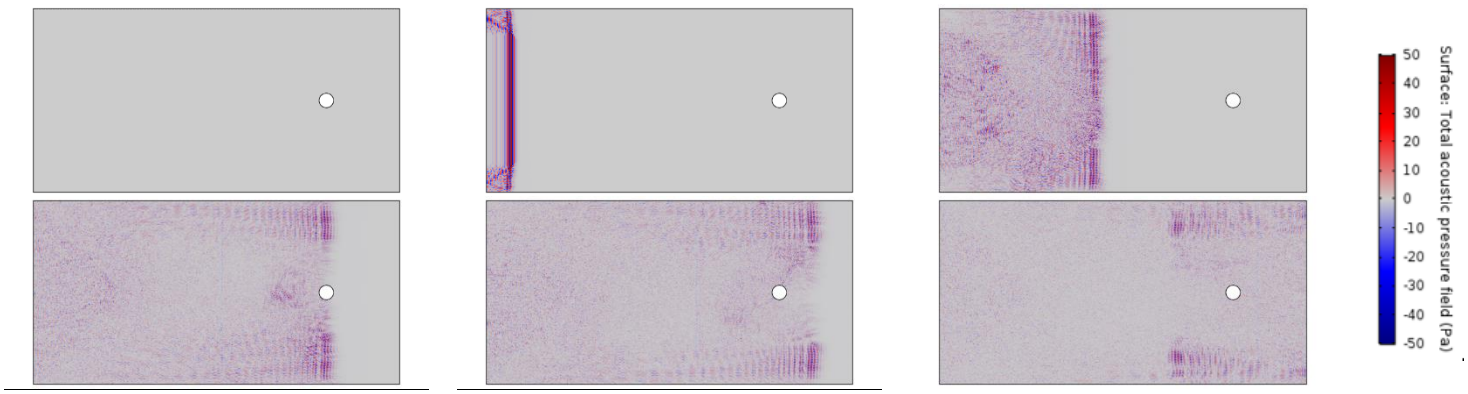
## 1.2 Results and discussion of numerical simulation

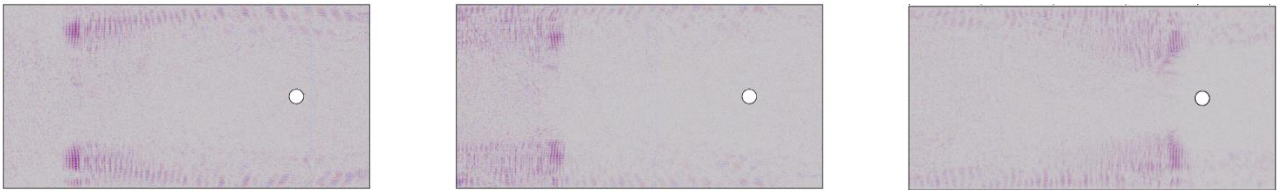
### *1.2.1 Lamb-wave excitation with the impulse pressure from left side*

In this model, the lamb wave mode excitation as an impulse pressure was sent from the left side of the steel plate. The right boundary was a sound hard boundary to simulate the signal reflex at the boundary. The results of the Lamb wave propagation and scattering in steel plates were shown in Fig. 4. As illustrated in Fig. 4(b), the signals changed from the surface when propagating through the circular damage, as compared to the undamaged states (see Fig. 4(a)).




(a) Unamaged state

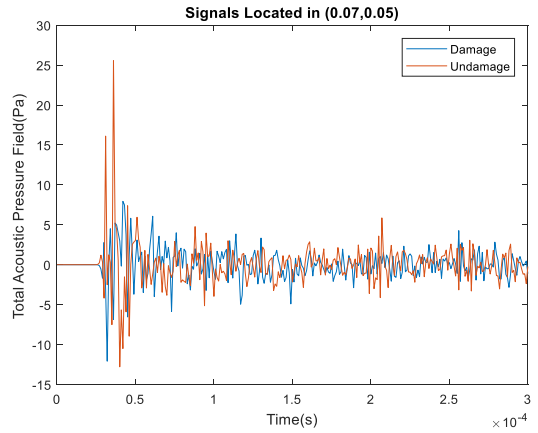


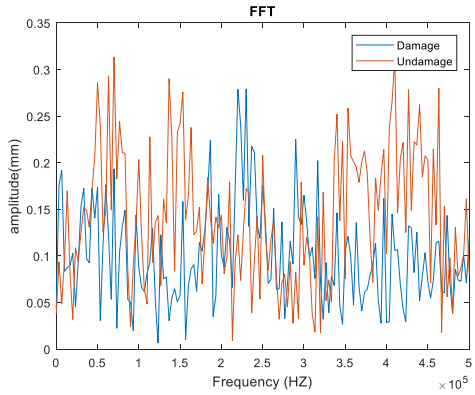


(b) Damaged state

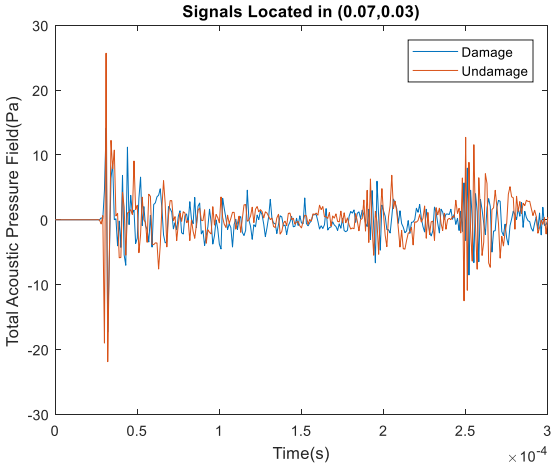
Fig. 4 Lamb wave propagation and scattering

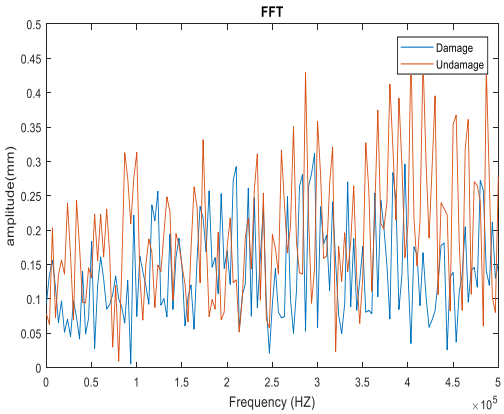
Assuming that there was a coordinate system and the original point was defined at the left corner, three probes were placed at different locations of the plate to collect the signals, by points of (0.07, 0.05), (0.07, 0.03) and (0.1, 0.06), respectively. FFT method was utilized to transfer the signals in the frequency domain, as shown in Figure 5. Similarly, the CWT was to transfer them in the time-frequency domain. From the surface of the plate, we can see the wave propagation and scattering clearly. However, the results based on the lamb wave mode with an impulse pressure at the side may not provide proper identification between damaged and undamaged states.



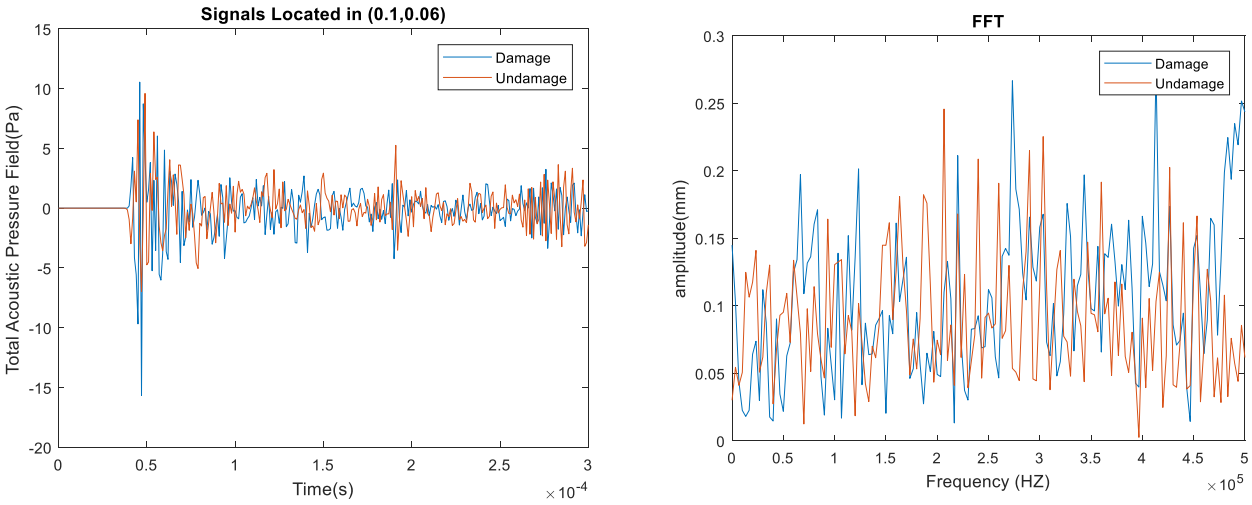




(a) First location



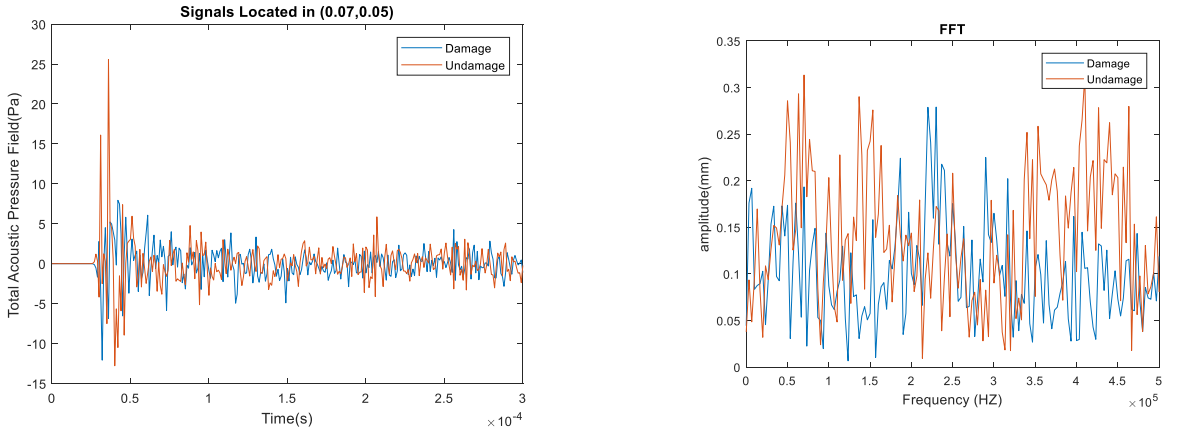




(b) 2nd location

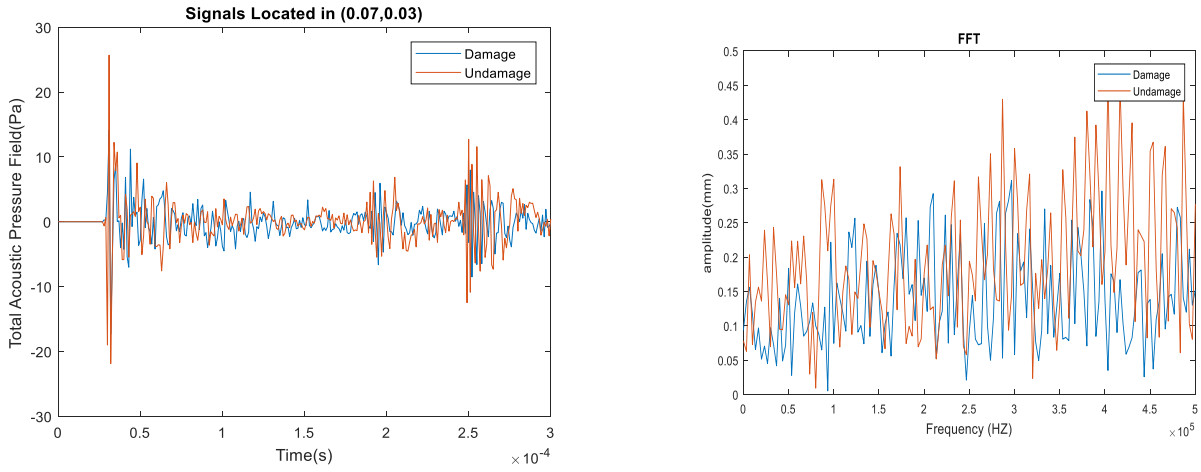



(c) 3rd location

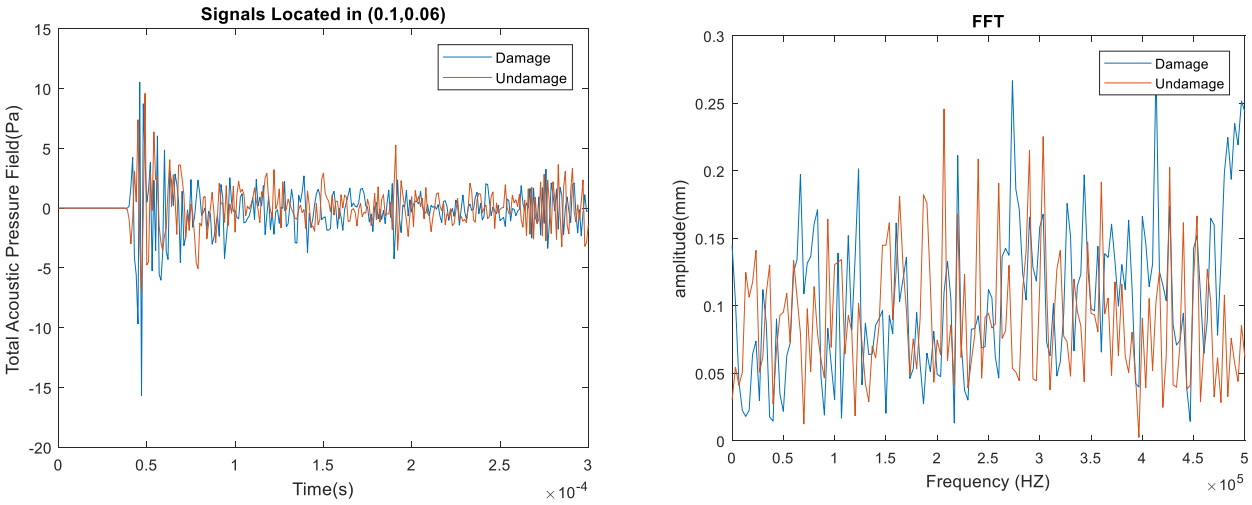
Fig. 5 Signals in three different locations




(d) First location




(e) 2nd location



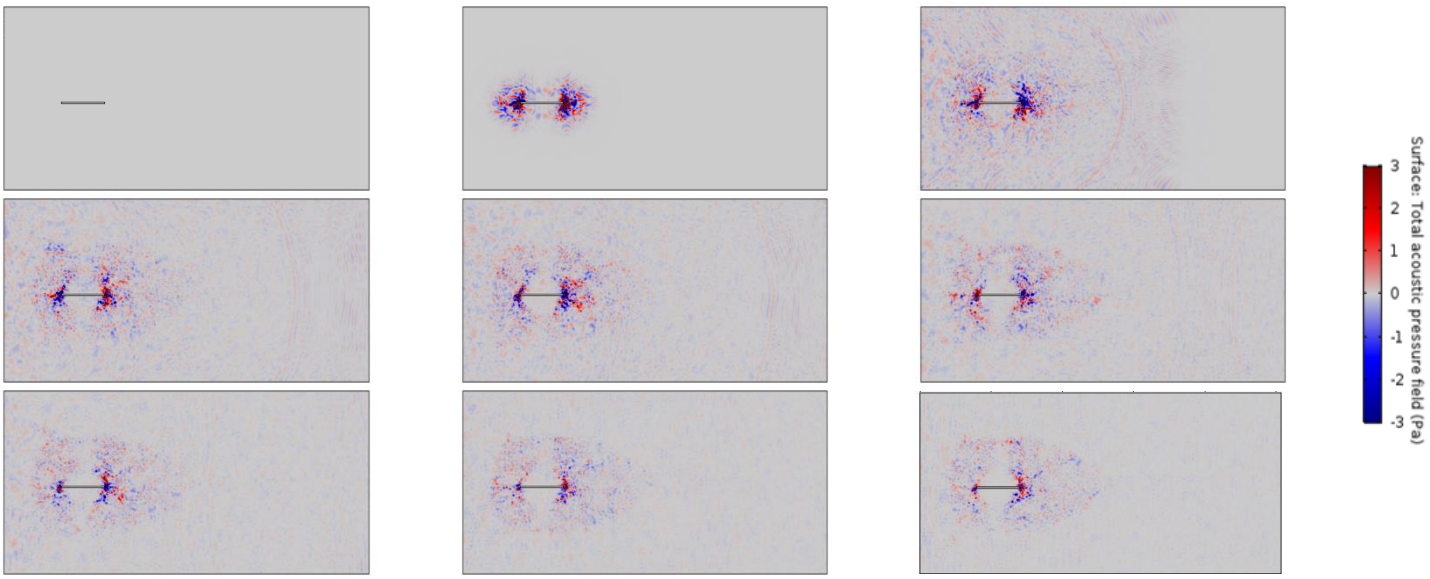

(f) 3rd location

Fig. 5 Signals in three different locations

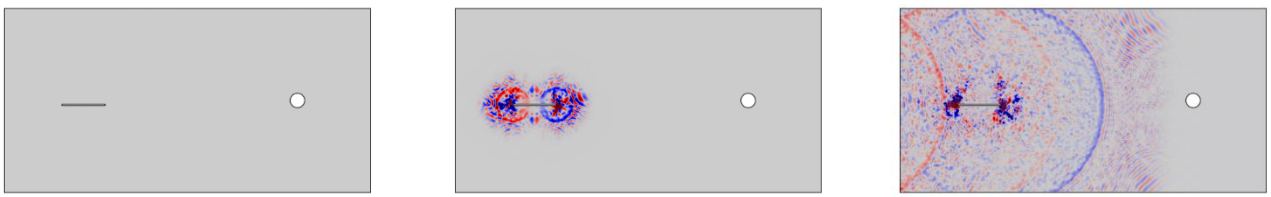
### *1.2.2 Lamb-wave excitation with the impulse pressure from simulated piezo actuator*

The piezo actuator tends to generate the Lamb wave mode signal. The piezo actuator compresses when the voltage changed. A notch was used to simulate a simulated piezo actuator on the left side of the steel plate model, as shown in Fig. 6. The left and right boundaries were set up as sound hard boundaries to simulate the wave reflexed at the boundary. The upper and lower sides of the plate were defined as a plane wave radiation to minimize the reflexed wave propagation at these boundaries.

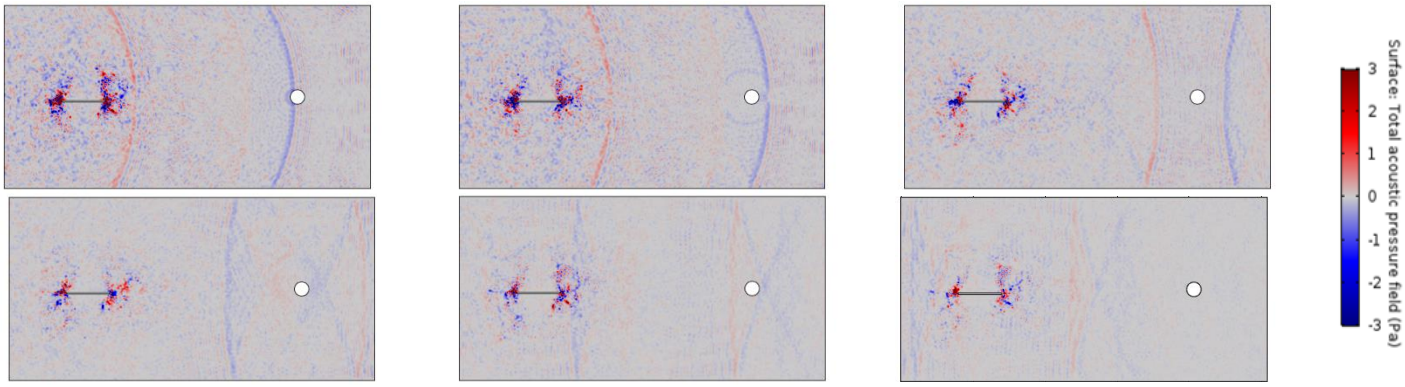
The results of the Lamb wave propagation and scattering in steel plates were shown in Figs. 6(a) and 6(b). Clearly, the resulting signal changed when propagating through the circular damage, as compared to undamaged cases.




(a) Undamaged state



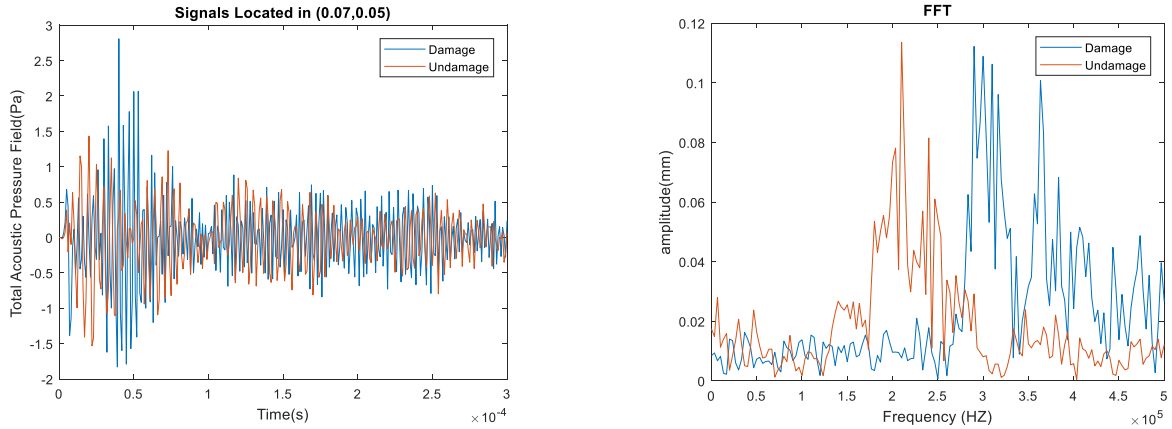
(b) Damaged state



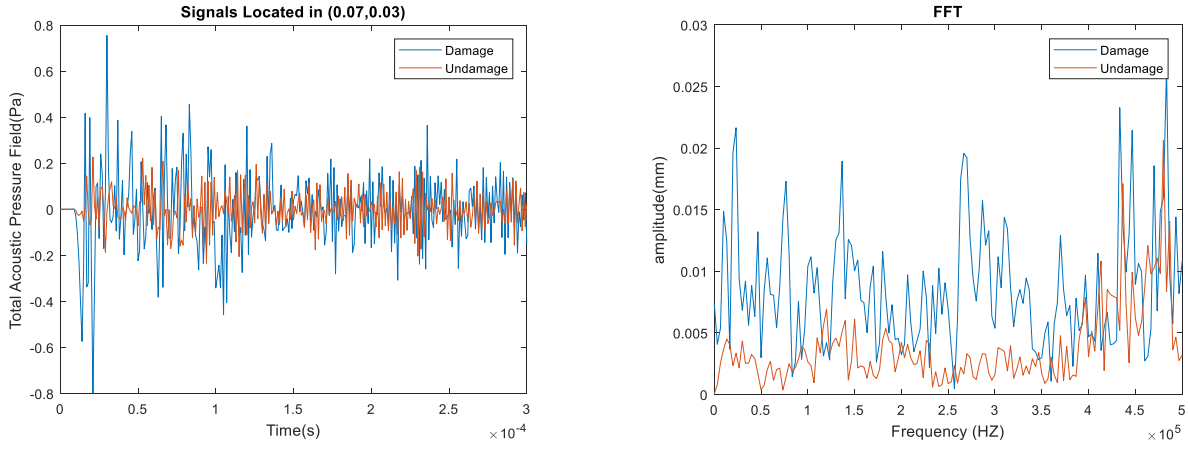

(b) Damaged state

Fig. 6 Lamb wave propagation and scattering

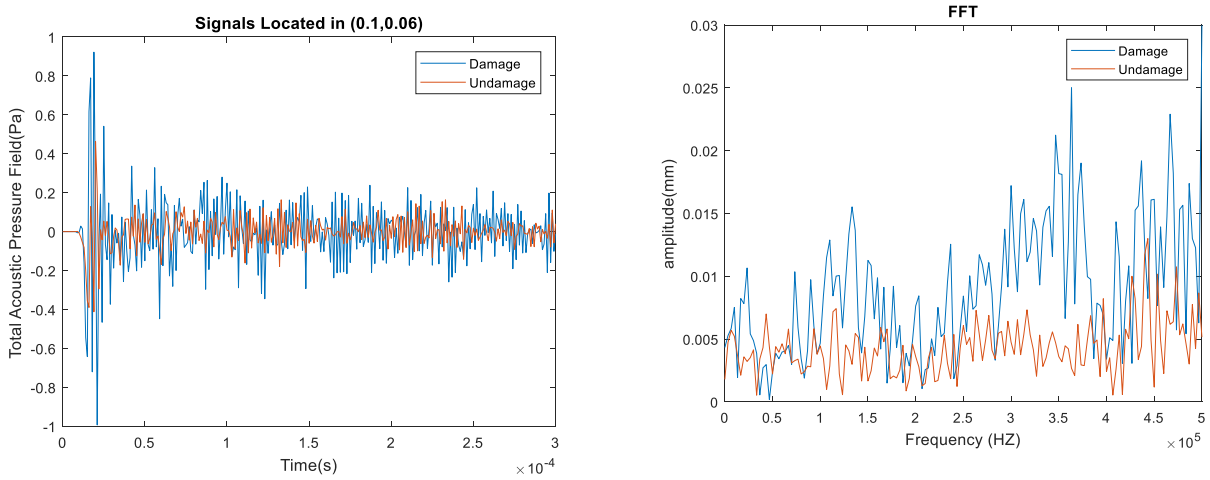
Similarly, the signals were recorded at three different locations and were plotted in Fig. 8. The resulting signals were also analyzed using the FFT and wavelet transforms in frequency domain and time-frequency domain (see Fig. 7).




(a) First location




(b) 2nd location




(c) 3rd location

Fig. 7 Signals in three different locations

To sum up, by comparing with these four different models, the inclusion of the lamb wave mode signal using the impulse displacement showed the higher sensitive response and thus it will be selected for further damage identification. Note that the modes by placing load at two sides exhibited the wave propagation in two dimensions, and thus led to the complex signals. The ongoing attempt would be made to simplify the modeling to reduce such interference.

## 1.3 Experimental program

As illustrated in Fig. 16, the test setup consisted of generator, oscilloscope, piezo actuators and a steel plate. To cover the wide ranges of mechanical damage, different damage types were designed, as listed below and illustrated in Fig. 8. The experimental tests were still under the way and the further results/discussion will be presented in the next report.

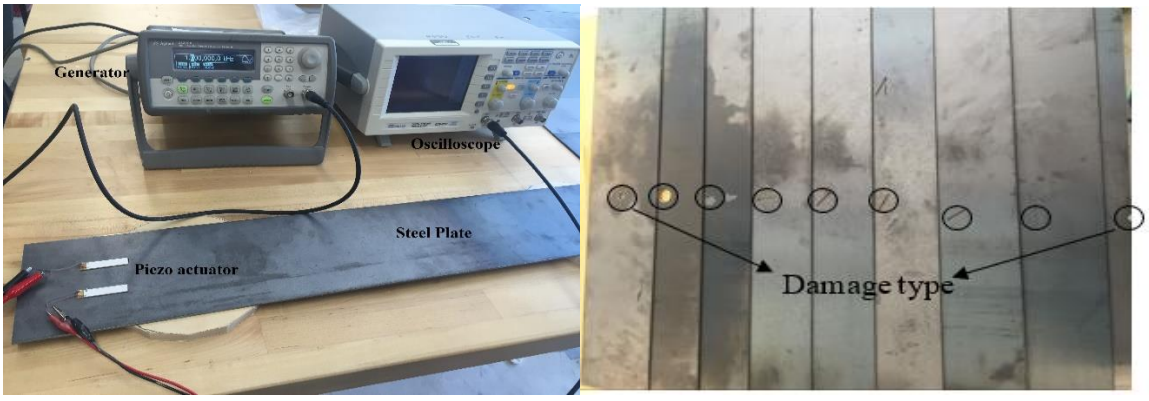



Fig. 8 Test setup

### (c) Description of any Problems/Challenges

No problems are experienced during this report period

### (d) Planned Activities for the Next Quarter

The planned activities for next quarter are listed below:

- First direction of the experimental tests will continue, while the data on specified mechanical damage (type and size) will be recorded and analyzed, and
- Second direction of the algorithm of machine learning will be developed, while the lab data will be used for calibration and training sets.